Modulation acceptance bandwidth

By Harold Kinley, C.E.T.

The specifications on an FM communications receiver usually specify a figure for *modulation acceptance bandwidth*. What is modulation acceptance bandwidth, and what is the significance of the specification figure? We will attempt to answer that question and maybe raise some new ones.

IEEE definition

The Institute of Electrical & Electronics Engineers (IEEE) defines modulation acceptance bandwidth as:

> The selectivity characteristic of a receiver that limits the maximum permissible modulation deviation of the radio-frequency input signal that a receiver can accept, without degradation of the 12-decibel SINAD, when the radio-frequency input signal is 6 decibels greater then the reference sensitivity level. (page 4, IEEE publication standard 184-1969, *IEEE Test Procedure for Frequency-Modulated Mobile Communications Receivers.)*

Test procedure

The setup for the test procedure is shown in Figure 1 below. This is the same test procedure setup that is used to determine the 12dB SINAD sensitivity of a receiver. To determine a receiver's modulation acceptance bandwidth, first perform

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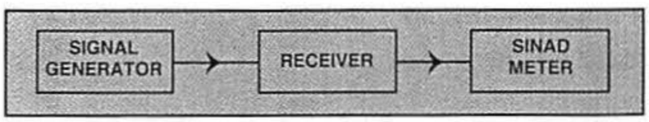

Figure 1. The setup for measuring modulation acceptance bandwidth.

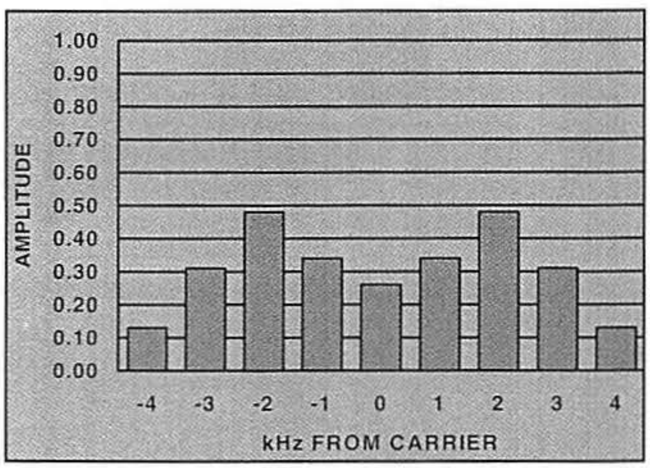

Figure 2. The *significant* sidebands of an FM signal modulated by a 1kHz tone at a deviation of ±3kHz. These sidebands account for 99.6% of the power in the sideband spectrum. Modulation index (β) = 3.

Table 1—The Bessel functions of the *significant* sidebands for modulation indice (β) of 3, 5 and 7.

COMPONENT	AMPLITUDE		
	β = 3	β = 5	β = 7
$J_0(\beta)$	0.2601	0.1776	0.3001
$J_1(\beta)$	0.3391	0.3276	0.004863
$J_2(\beta)$	0.4861	0.04657	0.3014
$J_3(\beta)$	0.3091	0.3648	0.1676
$J_4(\beta)$	0.1320	0.3912	0.1578
$J_5(\beta)$	----	0.2611	0.3479
$J_6(\beta)$	----	0.1310	0.3392
$J_7(\beta)$	----	----	0.2336
$J_8(\beta)$	----	----	0.1280

β = MODULATION INDEX
J_0 = CARRIER
J_1 = 1ST SIDEBAND PAIR
J_n = nTH SIDEBAND PAIR

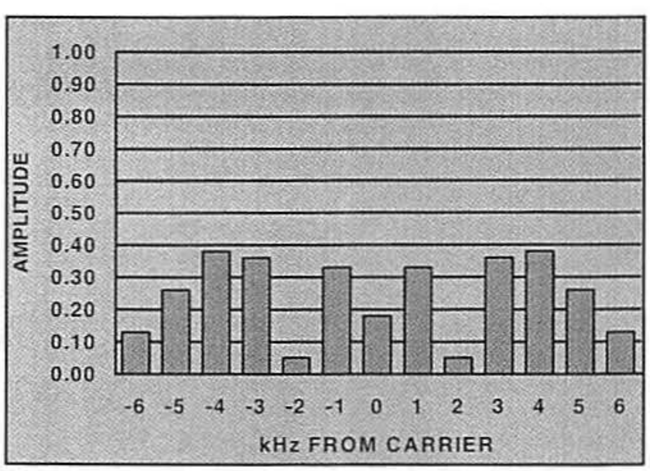

Figure 3. The *significant* sidebands of an FM signal modulated by a 1kHz tone at a deviation of ±5kHz. These sidebands account for 99.3% of the power in the sideband spectrum. Modulation index (β) = 5.

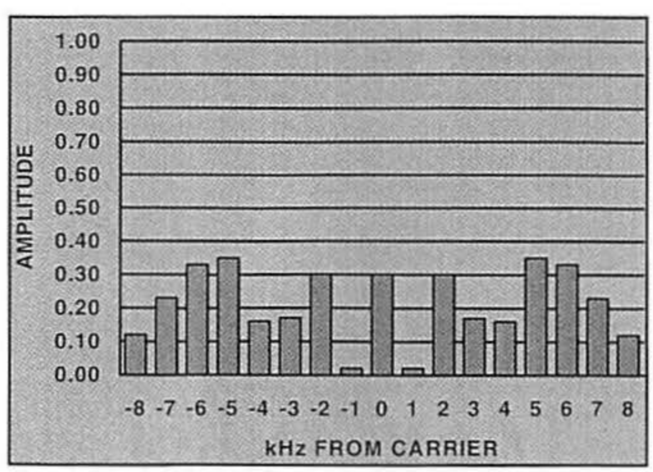

Figure 4. The *significant* sidebands of an FM signal modulated by a 1kHz tone at a deviation of ±7kHz. These sidebands account for 99.2% of the power in the sideband spectrum. Modulation index (β) = 7.

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the 12dB SINAD sensitivity test. Then, increase the signal generator level 6dB above the level required for 12dB SINAD sensitivity, or twice the microvolt level. The SINAD reading should improve greatly with the increased signal input level. Now, while observing the SINAD meter reading, slowly increase the deviation of the signal generator until the SINAD reading is degraded back to the 12dB SINAD level. At this point the deviation of the signal generator (±X kilohertz) is the modulation acceptance bandwidth.

For narrowband FM, the *minimum* modulation acceptance bandwidth figure should be ±5kHz. This figure is really not enough for fully modulated signals because the modulated signal occupies a greater bandwidth. Typical receivers usually are rated at about ±7kHz modulation acceptance bandwidth.

With modern crystal or ceramic filters, the bandwidth usually is on the low or narrow side if the input/output impedance matching adjustments are misadjusted.

A fair test?

The test procedure described above for modulation acceptance bandwidth sometimes can be misleading and can, in some cases, lead to an unfair rating of a receiver's specification figure for modulation acceptance bandwidth. Why?

The reason is that the input signal level varies according to the *measured* 12dB SINAD sensitivity of the receiver; that is, the input signal level for determining modulation acceptance bandwidth is 6dB greater than the reference sensitivity level of the receiver.

To make a truly valid comparison of the modulation acceptance bandwidth specification between two receivers of the same model (without regard to the reference sensitivity), it would only be fair to make the measurement at the same input signal level.

You probably have seen receivers that exhibit a much better 12dB SINAD sensitivity than the rated specification. For example, a receiver with a reference sensitivity rating of 0.35μV is tested and found to have a sensitivity of 0.25μV or even 0.20μV. This means that the modulation acceptance bandwidth test for that receiver is run with an input signal level of 0.5μV or 0.4μV (6dB above reference sensitivity).

Then, when the modulation acceptance bandwidth test is run at twice the measured sensitivity input level, the modulation acceptance bandwidth figure may fall short of the specification figure. In such cases, it is better to measure the modulation acceptance bandwidth at a signal input level 6dB above the manufacturer's *specification* figure for sensitivity rather than 6dB above the *measured* sensitivity level.

When using the modulation acceptance bandwidth test to determine the performance of a receiver or to compare the performance of two receivers, use common sense. Make the comparison on an equal basis. Run the test in the standard way and then run the modulation acceptance bandwidth test using the same input signal level and compare the two results. This will give you a better idea of the receivers' performance under like conditions.

Modulation spectrum

Although the frequency-modulated signal has sidebands extending out to theoretical infinity, it has been determined that

SIDEBAND POWER CALCULATIONS

(1) $P_T = J_0^2(\beta) + 2[J_1^2(\beta)] + \ldots 2[J_n^2(\beta)]$

(2) $P_{T_1} = (0.2601)^2 + 2[(0.3391)^2] + 2[(0.4861)^2] + 2[(0.3091)^2] + 2[(0.1320)^2] = 0.06765 + 0.23 + 0.4726 + 0.1911 + 0.0348 = 0.99615 = 99.6\%$

(3) $P_{T_2} = (0.1776)^2 + 2[(0.3276)^2] + 2[(0.04657)^2] + 2[(0.3648)^2] + 2[(0.3912)^2] + 2[(0.2611)^2] + 2[(0.1310)^2] = 0.0315 + 0.2146 + 0.00434 + 0.2662 + 0.3060 + 0.1363 + 0.03432 = 0.99326 = 99.3\%$

(4) $P_{T_3} = (0.3001)^2 + 2[(0.004863)^2] + [(0.3014)^2] + 2[(0.1676)^2] + 2[(0.1578)^2] + 2[(0.3479)^2] + 2[(0.3392)^2] + 2[(0.2336)^2] + 2[(0.1280)^2] = 0.0900 + 0.000047 + 0.1817 + 0.0562 + 0.0498 + 0.2421 + 0.2301 + 0.1091 + 0.0328 = 0.9918 = 99.2\%$

sidebands containing 98% of the power in the modulated signal are confined to a relatively narrow bandwidth. Furthermore, if the sidebands containing at least 98% of the signal power are passed through the receiver, the signal can be reproduced with little distortion.

Figures 2, 3, and 4 on page 8 show the modulation sideband spectra of a signal frequency modulated by a 1kHz single tone at deviations of ±3kHz, ±5kHz and ±7kHz, respectively. This represents a modulation index (β) of 3 for Figure 2; 5 for Figure 3; and 7 for Figure 4. Table 1 on page 8 shows the Bessel function for the carrier and sidebands for each of the modulation sideband spectra.

The carrier and sideband pairs in Figure 2 contain 99.6% of the total power in the frequency-modulated signal. The carrier and sideband pairs in Figure 3 contain 99.3% of the total power, and the carrier and sideband pairs in Figure 4 contain 99.2% of the total power. The percentage of power contained in the sideband pairs and carrier is calculated as shown in the box to the left. The generalized expression for the formula is shown in Equation 1 in the box. Equation 2 represents the

calculation of total power in the sideband spectrum shown in Figure 2; Equation 3 is for Figure 3; and Equation 4 is for Figure 4.

Required bandwidth

The bandwidth required to pass the modulated sideband spectra shown in Figures 2 through 4 can be calculated from the following formula:

$$B_W = 2f_M(\beta + 1)$$

where

B_W = bandwidth in kHz

f_M = modulating frequency in kHz

β = modulation index

Modulation index (β) = deviation $\div$ modulating tone frequency.

You can see that the formula for bandwidth holds true for the sideband spectra shown in Figures 2, 3 and 4. For example, in Figure 2 the modulation index is 3 (3kHz deviation and 1kHz tone). Substituting into the formula:

$$B_W = (2)(1)(3 + 1) = 8$$

Thus, the bandwidth is 8kHz. In Figure 2, the significant sidebands extend to $\pm$4kHz, which corresponds to a bandwidth of 8kHz. This relationship can be verified in like manner for the sideband spectra shown in Figures 3 and 4.

These illustrations show why the required bandwidth is more than just the amount of deviation of the signal. If at least 98% of the power in the modulated spectrum is passed by the receiver, the audio modulation can be reproduced with little distortion. However, when *significant* sidebands fall outside the bandpass of the receiver, distortion results. This phenomenon is why the modulation acceptance bandwidth specification of a receiver is so important.

That being the case, it is equally important to be able to compare the performance features of two receivers fairly in making a true performance determination. Thus, it is very useful to run the modulation acceptance bandwidth test at equal signal input levels.

Stay tuned!